

# Mobile Converged Networks: Framework, Optimization and Challenges

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## Abstract

In this paper, a new framework of mobile converged networks is proposed for flexible resource optimization over multi-tier wireless heterogeneous networks. Design principles and advantages of this new framework of mobile converged networks are discussed. Moreover, mobile converged network models based on interference coordination and energy efficiency are presented and the corresponding optimization algorithms are developed. Furthermore, future challenges of mobile converged networks are identified to promote the study in modeling and performance analysis of mobile converged networks.

## I. INTRODUCTION

Currently, wireless communication networks are widely deployed into every scenario of human society, which includes short distance transmission, e.g., Bluetooth communications in wireless

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mouses, long distance transmission, e.g., space transmission between the Earth and the Mars, and etc. Although the above networks and application scenarios are quite different, multi-mode communications have adopted more and more communication standards and technologies into a common user terminal. For instance, the smart mobile phone usually supports the cellular network, the wireless local area network (WLAN), the Bluetooth and the near field communication, etc. Based on multi-mode communications, different types of wireless heterogeneous networks can be converged into a uniform mobile network, i.e., the mobile converged network [1], [2]. A typical mobile converged network is illustrated by Fig. 1, in which the cellular network, WLAN and wireless sensor network (WSN) are converged.

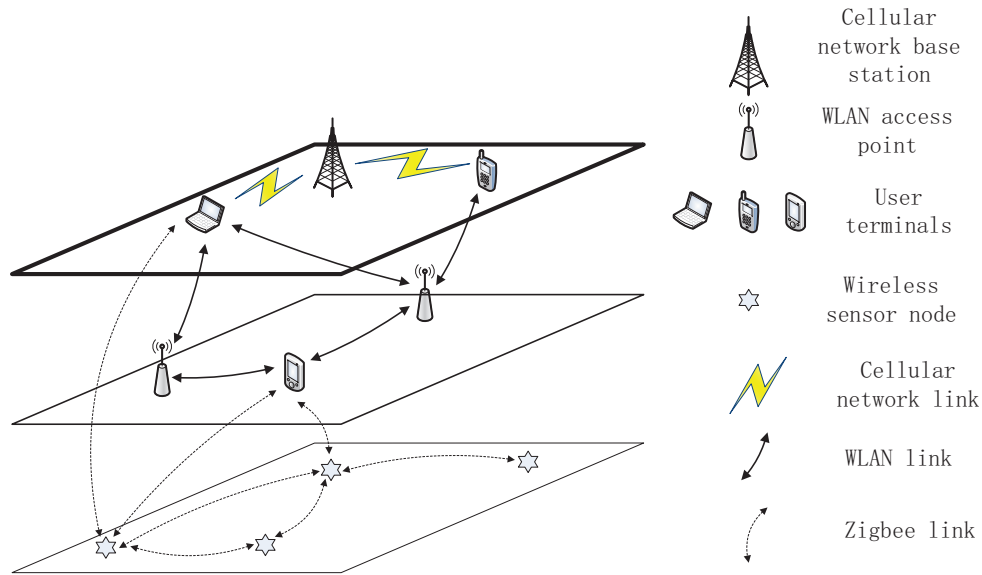


Figure 1. A typical mobile converged network

Studying mobile converged networks has attracted much attention in the past years, especially in the topic of converged mobile cellular networks and WSNs. Han proposed an authentication and key agreement protocol that efficiently reduces the overall computational and communication costs in the next generation converged network [3]. A system architecture and application requirement for converged mobile cellular networks and WSNs was introduced and then the joint optimization of converged networks for machine-to-machine communications was discussed in [4]. An energy-efficient data collection scheme in a converged WSN and mobile cellular network

was proposed for improving energy efficiency [5]. A quality of service (QoS)-guaranteed resource scheduling algorithm and a railway resource grab mechanism in high-speed environment was presented to ensure the QoS for users and the timely transmission for railway signal in mobile converged networks [6]. Bae proposed a new concept of the converged service based on the digital multimedia broadcast and wireless networks [7]. After considering the network operation cost, the performance tradeoff between the network quality of service and the network operation cost for the intersystem soft handover in the converged digital video broadcasting for handhelds and Universal Mobile Telecommunications System network was modeled using a stochastic tree [8]. A framework of combining clouds and distributed mobile networks was presented [9], which the mobile converged networks can take advantage of. An efficient network selection mechanism was presented to guarantee mobile users selecting a most appropriate wireless network to connect from heterogeneous wireless networks using the theory of games [10].

In all the aforementioned mobile converged networks studies, modeling and performance analysis for detail scenarios were discussed and most of mobile converged networks were consisted of two types of wireless networks. However, there is not a general framework of mobile converged networks which covers multi-tier wireless heterogeneous networks. Motivated by above gaps, we propose a new framework of mobile converged networks which not only covers main characteristics of mobile converged networks but also includes different types of wireless heterogeneous networks.

The remainder of this paper is outlined as follows. A new framework of mobile converged networks is proposed to support multi-tier heterogeneous networks. Moreover, two algorithms are developed to improve the performance of mobile converged networks, respectively. Based on presented results, future challenges for mobile converged networks are given, followed by conclusions drawn in the last section.

## II. A FRAMEWORK OF MOBILE CONVERGED NETWORKS

### A. A framework of mobile converged networks

To converge different types of wireless communication technologies into a mobile network, two problems have to be solved. Firstly, a converged scheme should be presented by investigating characteristics of different types of wireless communication technologies for avoiding potential technology conflicts. Secondly, the performance evaluation of mobile converged networks is

another issue which involves with the selection of evaluation subjects, the evaluation approaches, the validation of evaluation, the analysis of evaluation data, etc.

Based on the aggregation of each tier model of heterogeneous network, the mobile converged network framework can be directly built by defining the node multi-associated relationship in multi-tier heterogeneous networks. However, it is difficult to analyze and optimize the resource schedule of mobile converged networks when many variables are involved into the aggregation of each tier model of heterogeneous networks. Moreover, it becomes impossible to optimize the resource schedule in mobile converged networks when the calculation complexity increases obviously with the increasing of network sizes. Therefore, it is a critical problem to build a new framework of mobile converged networks with the limited complexity and enough flexibility for future wireless heterogeneous networks.

In order to reduce the number of variable types in converged heterogeneous networks, the variable mapping is considered as an important approach to build a framework of mobile converged networks. For example, transmitters in different tiers of wireless heterogeneous networks usually have different transmission power. To evaluate the impact of transmission power from different tier wireless heterogeneous networks on the mobile converged networks, locations of transmitters can be scaled into a framework of mobile converged network by accounting for path loss effect over wireless channels. In the new framework of mobile converged networks, the transmission power from difference tiers of wireless heterogeneous networks is normalized and locations of transmitters are scaled to ensure that the signal-to-interference-plus-noise ratio (SINR) at receivers in a mobile converged network are equivalent to the SINR at receivers in multi-tier wireless heterogeneous networks. As a consequence, a new framework of mobile converged networks can be presented by variable mapping in wireless heterogeneous networks. Moreover, based on the allocation, the interaction of different tiers of wireless heterogeneous networks is classified as the non-conflict domain and the conflict domain in the framework of mobile converged networks for optimizing the resource schedule. A conflict domain includes multi-tier heterogeneous networks with interference among each other, and a non-conflict domain includes multi-tier heterogeneous networks without interference among each other.

The network topology of wireless heterogeneous networks is affected by wireless access methods, infrastructures, mobility and relay of user terminals. Therefore, all above factors should be included into the new framework of mobile converged networks by mapping a uniform

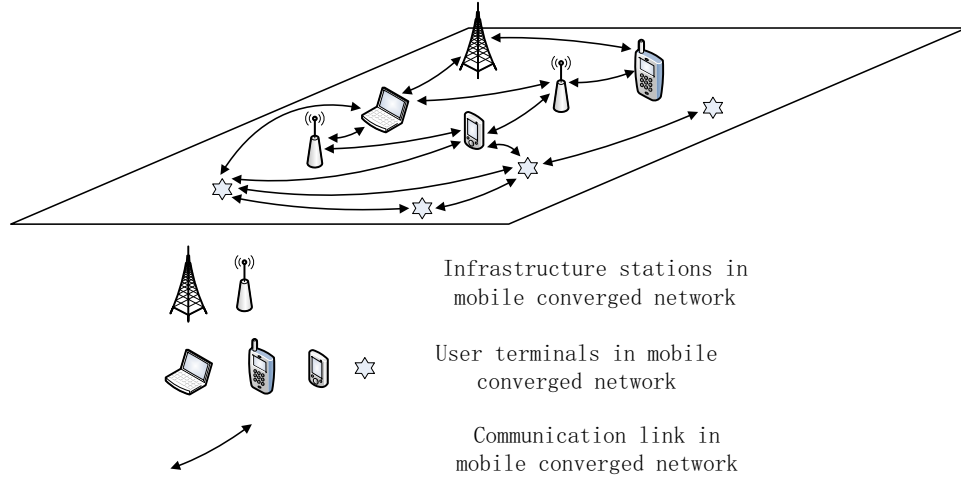


Figure 2. A random network topology of mobile converged network

network topology. Based on the random network topology mapping approach, a uniform network topology of mobile converged network is illustrated in Fig. 2. Even for nodes which have the multi-mode capability, different links of a multi-mode node are mapped into virtual multi-tier wireless heterogeneous networks as multiple links which are separated into multiple mapped single-mode nodes with different transmission locations firstly. And then, using virtual infinite-bandwidth inter-node links to connect them together, these single-mode nodes at virtual multi-tier wireless heterogeneous networks are mapped as a functional single node into a uniform network topology of mobile converged network.

In the uniform network topology of mobile converged network, all infrastructure stations and user terminals are normalized as mobile converged network nodes and all wireless links of wireless heterogeneous networks are normalized as mobile converged network links. Therefore, the uniform network topology of mobile converged networks is formulated as  $(\Phi^C, L^C)$ , where  $\Phi^C$  is the node set of mobile converged networks and  $L^C$  is the link set of mobile converged networks. Compared with aggregated multi-tier wireless heterogeneous networks, the performance analysis of mobile converged networks is simplified by a uniform network topology.

For example, we consider the down-links in  $K$ -tier heterogeneous cellular networks, the base stations (BSs) in tier  $k$  have the transmit power  $P_k$  and the distribution of BSs follows a point process [11]  $\Phi_k^{\text{BS}}$ . Without loss of generality, a mobile station (MS)  $\text{MS}_y$  is assumed to be located

at the origin coordinate  $\mathbb{O}$ , the signal power  $P_{\text{BS}_x\text{MS}_y}$  received by the MS  $\text{MS}_y$  from a BS  $\text{BS}_x$  located at  $x$  is

$$P_{\text{BS}_x\text{MS}_y} = P_k \|x - \mathbb{O}\|^{-\alpha} = 1 \cdot \left( P_k^{-\frac{1}{\alpha}} \|x - \mathbb{O}\| \right)^{-\alpha} = 1 \cdot \left\| P_k^{-\frac{1}{\alpha}} \cdot x - \mathbb{O} \right\|^{-\alpha}, \quad (1)$$

where 1 is the normalized transmission power,  $\alpha$  is the path loss factor from the BS  $\text{BS}_x$  to the MS  $\text{MS}_y$  at origin  $\mathbb{O}$  and  $\|\cdot\|$  is the distance operator.

The equation (1) means that the signal power received by the MS  $\text{MS}_y$  at origin is exactly equal to the signal power transmitted from a virtual BS with transmit power 1 and located at  $P_k^{-\frac{1}{\alpha}} \cdot x$ , where  $P_k^{-\frac{1}{\alpha}}$  times far from the origin  $\mathbb{O}$  comparing to the BS  $\text{BS}_x$ . Centered with the origin  $\mathbb{O}$ , which we call transmission power normalized center, the point process  $\Phi_k^{\text{BS}}$  can be scaled to the point process  $\Phi_k^{\text{BS}'} = P_k^{-\frac{1}{\alpha}} \cdot \Phi_k^{\text{BS}}$ , in which the virtual BSs with transmission power 1 transmit the same signal power (or interference power) to the origin MS as the original BSs in  $\Phi_k^{\text{BS}}$  do. We scale the point processes in all tiers to normalize the transmit power to 1, and then combine them into a point process  $\Phi^C = \bigcup_{k=1}^K P_k^{-\frac{1}{\alpha}} \cdot \Phi_k^{\text{BS}}$ , while keeping the link set  $L^C$  same as the network links before scaling. In the end, the uniform network topology of mobile converged networks is given.

However, there still exist many issues to build the new framework of mobile converged networks. Two main issues are summed as follows:

- 1) The uniform description issue of different wireless access methods. It is well known that the wireless access method has great impact on the wireless link management, the interference coordination, the transmission rate, spectrum efficiency and energy efficiency in wireless networks. It is difficult to analyze the impact of different wireless access methods on the performance of mobile converged networks by one parameter.
- 2) The location issue of transmission power normalized center. In the view of statistics, the transmission power normalized center of mobile converged networks can located in arbitrary point without impacting of signal/interference analysis on the mobile converged network. However, different locations of the transmission power normalized center will affect the random network topology and network router models. Consequently, location optimization of the transmission power normalized center is another key issue in the framework of mobile converged networks.

Motivated by the above gaps, we propose a new framework of mobile converged networks

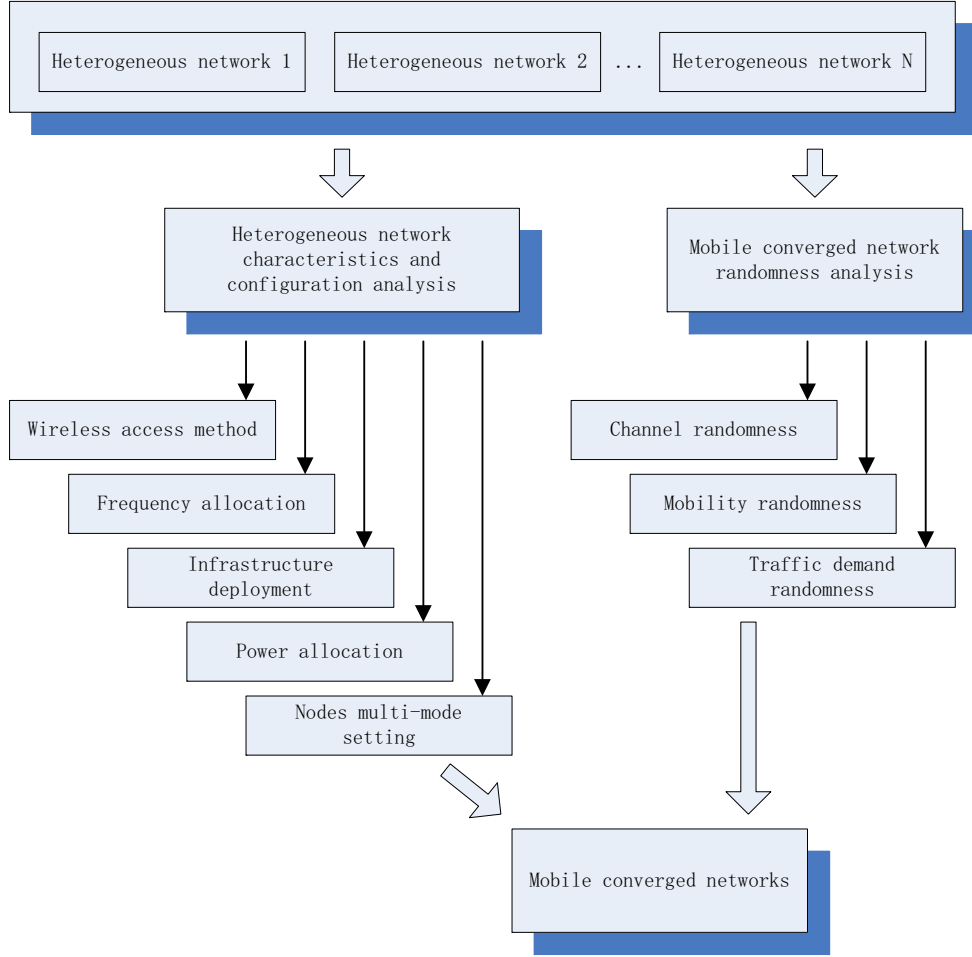


Figure 3. The new framework of mobile converged networks

to cover multi-tier wireless heterogeneous networks in Fig. 3. The new framework of mobile converged networks is divided into two parts: one part of framework is about the characteristics and configurations of wireless heterogeneous networks, which includes wireless access methods, frequency allocation, infrastructure deployment, power allocation and configuration of multi-mode nodes; another part of framework is about the randomness characteristics of wireless heterogeneous networks, which includes wireless channel randomness, mobility randomness and traffic demands randomness.

### *B. Modeling of mobile converged networks based on interference coordination*

The interference coordination is always an important challenge for wireless communication systems. It is well known that the interference coordination is related with the capacity, transmission rate, spectrum efficiency and energy efficiency in wireless networks. Based on the proposed framework of mobile converged networks, we explore to build a mobile converged network model accounting for co-channel interference among multi-tier wireless heterogeneous networks.

Based on the proposed framework of mobile converged networks, multi-tier wireless heterogeneous networks are mapped into a mobile converged network with a uniform network topology. However, the uniform network topology is just based on links in wireless heterogeneous networks. The links affected by co-channel interference of mobile converged networks are not mapped into the uniform network topology. For the mobile converged network model based on interference coordination, node links of mobile converged networks are adjusted by relationships between interfering transmitters and receivers. Furthermore, the coordinate locations of the transmitters in mobile converged networks are scaled by considering the transmission power of interfering transmitters and distances between the interfering transmitters and receivers. The random topology of mobile converged networks based on interference coordination is illustrated in Fig. 4, where real lines denote desired signal links and dash lines denote interference links.

Considering the interference coordination, the uniform network topology with desired signal links and interference links is derived for mobile converged networks. Furthermore, the cross-tier routing algorithms can be developed by utilizing the relay capability of multi-mode nodes for minimizing co-channel interference in mobile converged networks. The main idea of cross-tier routing algorithms is to maximize distances between interfering transmitters and receivers. To satisfy this requirement, data traffic is relayed by multi-mode nodes with different frequency bands in a mobile converged network. In this case, the co-channel interference could be minimized with guaranteed throughput in mobile converged networks. Therefore, the joint optimization solution involves with frequency, spatial and temporal dimensionalities of mobile converged networks. However, the mobile converged network model based on interference coordination is an open question considering following challenges: 1) Time variant wireless channels. Time variant wireless channels affect the capacity and the bit error rate of wireless links and even interrupt wireless links in mobile converged networks. In this case, the topology of mobile converged



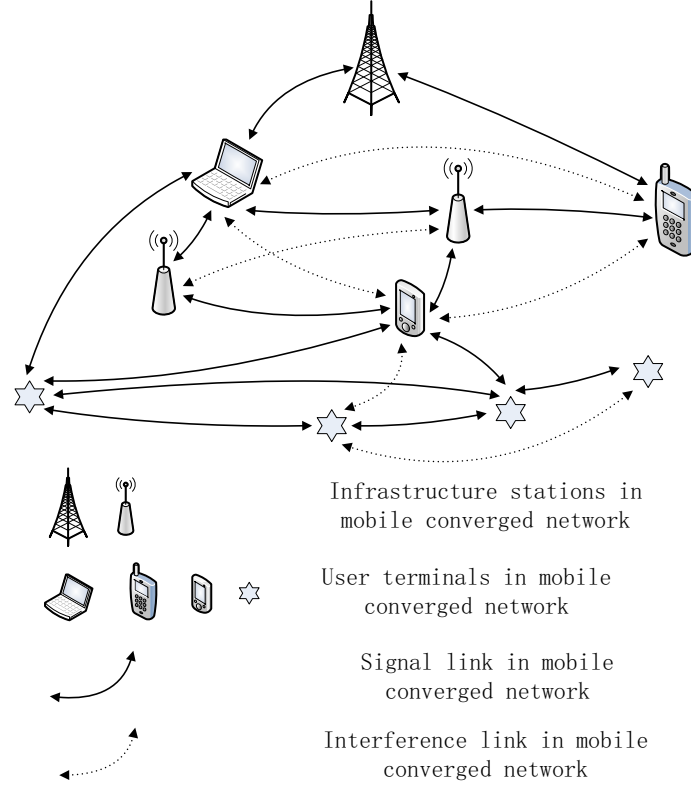


Figure 4. Network topology of mobile converged networks based on interference coordination

networks is affected by time variant wireless channels. Accordingly, the interference model of mobile converged networks should support the dynamical network topology affected by time variant wireless channels. 2) Spatial randomness of interfering transmitters. In mobile converged networks, the associating relationship among multi-mode nodes is flexible for minimizing co-channel interference. However, it is a complex problem to build the interference conflicting model when the network topology of mobile converged networks is changed by relationships between multi-mode nodes and user terminals. 3) Mobility randomness of user terminals. In mobile converged networks, user terminal locations are usually assumed to follow a random process. Moreover, the mobility model of user terminals also follows another random process. However, it is very difficult to model the mobility of the user terminals, because the mobility model and the location model follow different random processes.

Based on the mobile converged network model with interference coordination, the interference minimizing algorithm of mobile converged networks is presented in Algorithm 1.

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**Algorithm 1** the interference minimizing algorithm of mobile converged networks

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- 1: Input initial configuration parameters in mobile converged networks, such as locations of nodes, transmission power and resource allocation;
  - 2: Conflicting evaluation in frequency, spatial and temporal domains of mobile converged networks;
  - 3: **while** True **do**
  - 4:     Evaluate conflicting distribution in multi-domains;
  - 5:     Calculate the aggregated interference  $I_C$ ;
  - 6:     **repeat**
  - 7:          $I_{OPT} \leftarrow I_C$
  - 8:         Search the region with the maximal co-channel interference;
  - 9:         Check the interference tolerance in every tier of wireless heterogeneous network, and then adjust the cross-tier routing into the tier of network with the maximal interference tolerance;
  - 10:        Evaluate the new conflicting distribution in frequency, spatial and temporal domains;
  - 11:        Calculate the new aggregated interference  $I_C$ ;
  - 12:     **until**  $I_C \geq I_{OPT}$
  - 13:     Revise the configuration parameters based on nodes mobility;
  - 14: **end while**
- 

In conventional SINR scheme of mobile converged networks, user terminals are associated with infrastructure stations based on the maximal SINR value received at the user terminal. In this case, every user terminal just associates with an infrastructure station based on itself SINR performance without considering interference at other user terminals. As a consequence, one of user terminals maybe obtains the best optimal performance, but the average interference of mobile converged networks is obviously increased. Contrary to the conventional SINR scheme, the Algorithm 1 try to decrease the average interference at user terminals of mobile converged networks to improve the total performance of mobile converged networks. In every loop of interference optimization, the cross-tier route for transmission detours to the tier in which the smallest interference is generated and the maximal interference tolerance remains. Based on the Algorithm 1, simulation

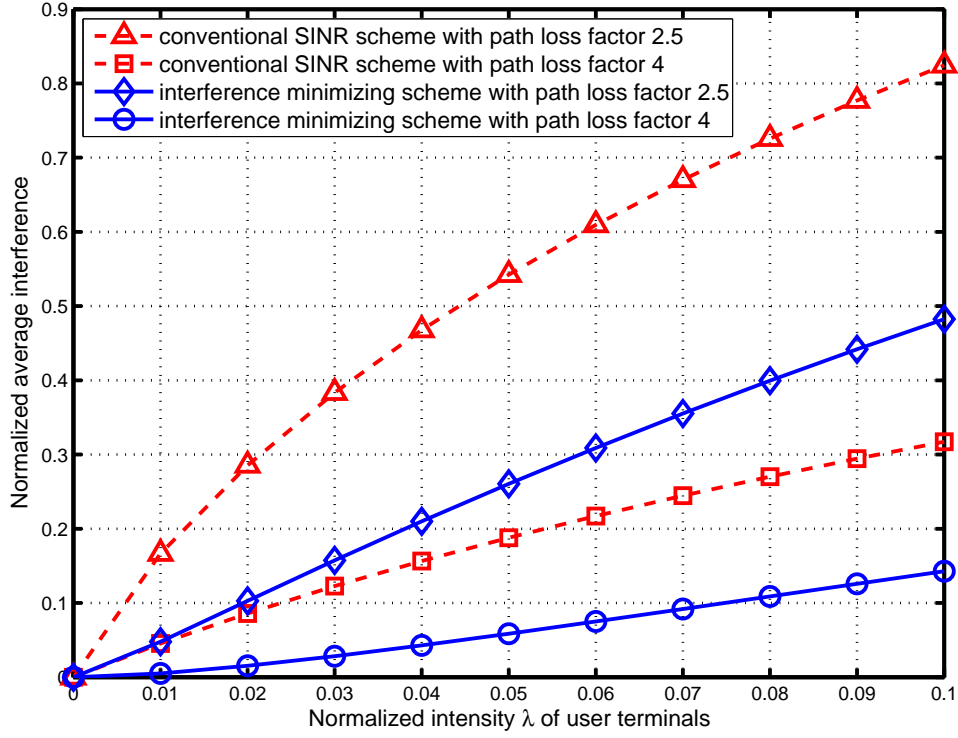


Figure 5. Normalized average interference of mobile converged networks with interference minimizing scheme and conventional SINR scheme

results of the interference minimizing scheme and conventional SINR scheme are compared in Fig. 5. In simulations of Fig. 5, a three-tier wireless heterogeneous network is configured with corresponding infrastructure station density denoted as 1:0.1:0.01, and the intensity of user terminals is also normalized by these densities of the tiers. User terminals are governed by a Poisson point process with intensity  $\lambda$  and their mobility subjects to Gaussian-Markov mobility model [12], and every user terminal can access one tier of wireless heterogeneous networks based on different association schemes. From curves in Fig. 5, the normalized average interference of mobile converged networks with the interference minimizing scheme is less than the normalized average interference of mobile converged networks with the conventional SINR scheme under different path loss factors. Fig. 5 illustrates that the normalized average interference increases with the increasing of the normalized intensity of user terminals, because the shorter distance of user terminals conduces to the higher interference.

### *C. Modeling of mobile converged networks based on energy efficiency*

Energy efficiency of wireless networks is defined as how many bits can be transmitted by consuming one Joule energy in wireless networks. Because mobile converged networks have characteristics of multi-network spatial overlay and multi-mode configuration in transmitters, mobile converged networks are recommended as one of potential solutions for improving energy efficiency in future wireless networks. Heterogeneous characteristics of mobile converged networks provide many degrees of freedom to optimize the energy efficiency of data transmission [13].

When multi-tier wireless heterogeneous networks are mapped into a uniform network topology, weighting vectors are added into links of the uniform network topology to build a directed graph. On the other hand, we can also configure the maximal power consumption threshold in specified nodes of mobile converged networks. It is necessary to build the maximal network flow model considering multi-dimensionality randomness in mobile converged networks. Furthermore, the energy efficiency optimization solution of mobile converged networks is based on the trade-off of the energy consumption and the network flow in frequency, spatial and temporal dimensionalities [14]. The Algorithm 2 is the energy efficiency optimization algorithm of mobile converged networks, in which energy consumption of every possible cross-tier link is evaluated to maximize the energy efficiency of mobile converged networks.

To evaluate the performance of the proposed energy efficiency optimization algorithm, simulation results are compared between the conventional SINR scheme and the energy efficiency optimization scheme for mobile converged networks in Fig. 6. The system model and simulation parameters in Fig. 6 are configured as the same in Fig. 5. Based on curves in Fig. 6, the normalized energy efficiency of mobile converged networks with the energy efficiency optimization scheme is larger than the normalized energy efficiency of mobile converged networks with the conventional SINR scheme under different path loss factors. Fig. 6 shows that the normalized average energy efficiency decreases with increasing of the normalized intensity of user terminals, because the higher interference conduces to the lower capacity and the lower energy efficiency.

The interference coordination model and the energy efficiency model are originated from the proposed framework of mobile converged networks. Based on the different constraint metrics, the interference coordination model can be used for interference optimization and the energy

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**Algorithm 2** the energy efficiency optimization algorithm of mobile converged networks

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- 1: Input initial configuration parameters in mobile converged networks, such as locations of nodes, transmission power and resource allocation;
  - 2: Calculate the energy efficiency and the network flow in frequency, spatial and temporal dimensionalities of mobile converged networks;
  - 3: **while** True **do**
  - 4:     Calculate the network flow  $F_C$  and the energy efficiency  $E_C$ ;
  - 5:     **repeat**
  - 6:          $E_{OPT} \leftarrow E_C$
  - 7:         Search the minimal energy efficiency region in a mobile converged network;
  - 8:         Analyze the network flow in multi-tier heterogeneous networks and corresponding energy efficiency;
  - 9:         Adjust the network flow by cross-tier routing algorithms to maximize the energy efficiency;
  - 10:        Calculate the new energy efficiency  $E_C$  in the specified region;
  - 11:     **until**  $E_C \geq E_{OPT}$
  - 12:     Change the network topology based on the mobility of user terminals;
  - 13: **end while**
- 

efficiency model can be used for energy optimization in mobile converged networks. Moreover, based on other resource optimization constraints in the framework of mobile converged networks, many models can be built for performance analysis.

### III. FUTURE CHALLENGES

It is always a great challenge to build a comprehensive system model of mobile converged networks to cover different types of characteristics in multi-tier wireless heterogeneous networks. Such a characteristic usually cannot be represented by a single system parameter. In addition, accuracy and effectiveness are equally important for a comprehensive system model, otherwise the computational complexity of such a model will increase dramatically and cannot be tackled by typical performance evaluation approaches. So, what are the key trade-offs between accuracy, effectiveness and complexity in mobile converged network models is an interesting question for

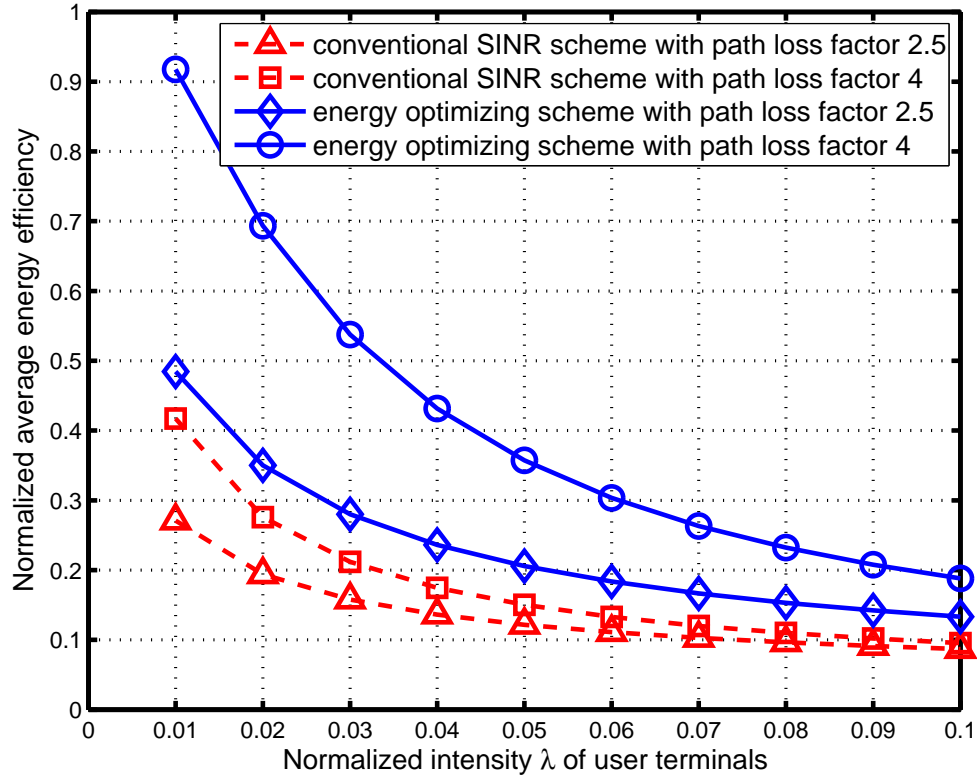


Figure 6. Normalized average energy efficiency of mobile converged networks with energy efficient scheme and conventional SINR scheme

future research. For a particular system model, there remains many open research issues, such as design and deployment of multi-tier network architecture, node position optimization, and resource optimization across multiple networks, in the analysis of system performance under realistic network conditions.

Based on the proposed framework and the comprehensive system model, new algorithms can be developed to improve the performance of mobile converged networks. Besides interference coordination and energy efficiency, different applications and user behaviors, such as audio/video streaming, interactive games, and online news, and the corresponding QoS provisioning and the resource allocation will also affect the whole system performance of mobile converged networks. Therefore, new resource optimization algorithms considering throughput, delay and link reliability should be further developed and analyzed accounting for different application

types and scenarios.

Although there exist some obstacles for operators and researchers to evaluate performance of mobile converged networks considering the different standards and commerce security, this is not an excuse not to converge multi-tier wireless heterogeneous networks into a mobile converged network. To ensure this outcome, the standards of mobile converged networks measurement and estimation should be made a matter of regulation and enforcement by the regulatory authorities.

#### IV. CONCLUSION

Until recently, the convergence of different types of heterogeneous networks becomes one of main research directions in future wireless networks. In this paper, we propose a new framework of mobile converged networks to cover different types of heterogeneous networks. A uniform framework of mobile converged networks would be helpful to design and evaluate performance of mobile converged networks in a single model. Furthermore, considering objectives of interference coordination and energy efficiency, two models of mobile converged networks and corresponding algorithms are developed. However, there still exist many issues to converge different types of heterogeneous networks, such as modeling, resource optimization and performance evaluation of mobile converged networks. If these are done, a veritable challenge would indeed emerge in the next round of the telecommunications revolution.

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